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AN APPRAISAL OF THE POTENTIAL FOR AGRICULTURAL RESOURCE SURVEYS BY REMOTE SENSING

SUMMARY REPORT

A report of research performed by the
Economic Research Service for the
Earth Resource Survey Program
Space Applications Program
National Aeronautics and Space Administration
Under Interagency Fund Transfer
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PREFACE

This report summarizes a research project carried out by the Natural Resource Economics Division, Economic Research Service, U.S. Department of Agriculture, for the National Aeronautics and Space Administration during the period September 1964 to June 1968, under Interagency Fund Transfer Nos. R-09-038-001 and R-09-038-002. The research was conducted in part by staff members of the Natural Resource Economics Division, and in part under contract by the Foreign Regional Analysis Division of ERS, Cornell University and the Systems Technology and Applied Research Corporation. The purpose of this summary report is to provide an overview and to present the highlights of the total effort.

Overall supervision for the project was provided by Robert C. Otte, Chief of the Land Resources Branch, and Percy R. Luney, Project Leader. Norman Landgren, who developed the original plan of work, provided supervision in the early stages, as did also Walter E. Chryst and Karl Gertel. Staff members with major responsibilities for specific phases of the project were H. Thomas Frey, Henry W. Dill, Jr., Simon Baker, and Orville Krause.

The material in this report was produced over a period of more than three years by a number of researchers representing several disciplines. As a result, there have been inconsistencies in conclusions, some of which were resolved in part for this summary statement and some which have been allowed to stand. The statements made herein are based on judgments of the individual researchers and do not necessarily reflect the endorsement of NASA or the USDA.

AN APPRAISAL OF THE POTENTIAL FOR AGRICULTURAL RESOURCES SURVEYS BY REMOTE SENSING

BACKGROUND AND ORGANIZATION OF THE RESEARCH

A number of experiments with remote sensing devices at low altitudes had indicated the eventual possibility of acquiring information on the use, productivity, and potentials of agricultural and related resources from space platforms. These experiments also demonstrated, however, that considerable development in the state-of-the-art of sensing, interpretation, and data management would have to precede the acquisition and utilization of data from space. Planners of programs for remote sensing from space would be faced with many technical decisions as to the use of newly developed remote sensing capabilities. Numerous potential applications within each of many scientific disciplines would compete for these capabilities. The basis for these choices is knowledge about the relative benefits of acquiring the various types of data. The study aimed to generate information to guide these decisions toward important ultimate objectives.

Man's material well-being fundamentally rests upon the prudent and efficient utilization of agricultural land and water resources. Opportunities for improving agricultural resource use, and thereby promoting economic development, are both identified and measured by accurate, comprehensive, and timely statistics on current resource use and use potential. The lack of these statistics is a major obstacle to progress of the less developed regions of the world and a significant hindrance to improved efficiency in the more fully developed regions. A capability to acquire comprehensive agricultural resource data from space should lead to a better utilization, more orderly development, and increased productivity of agricultural resources and the improved distribution of their products.

However, masses of data, generated without regard to end uses, would have little utility in planning for the efficient utilization of natural resources. The requirements of potential data users need to be identified for consideration in the design of sensing and telemetering systems and systems for the interpretation, storage, and retrieval of data.

The research was directed toward providing a basis for operational programs of data acquisition by exploring the type, detail and format of data output needed; desired frequency of data returns, geographic areas for which data are relevant, acceptable tolerances of accuracy, and sampling schemes to minimize the amount of telemetered imagery.

Objectives

One of NASA's major objectives has been to investigate and implement the adaptation of space technology for peaceful uses. With more specific objectives, this study was undertaken to provide guides for a long-range program of research and operations in the acquisition of data on agricultural and related resources by remote sensing methods through defining potential applications, assessing the relative importance of these applications, and specifying the requirements for data in each application area.

The specific research objectives were as follows:

1. To identify potential agricultural applications of remote sensing from space platforms.

2. To assess the quantitative and qualitative benefits potentially obtainable from an operational program of data collection in each application area.

3. To rank application areas in accordance with apparent importance or payoff as a guide to research, development, and priority for operations.

Organization of the Research

The plan of work for this study was set forth in seven segments. As the research evolved, it became clear that the subject matter could be organized more effectively. The following table shows both the original segments of the work plan, reports prepared, and the relationships between them:

Work Plan Segment	Final Report
I. Identification of maximum potential agricultural applications of remote sensing from space platforms.	
II. Specification of minimum imagery requirement for each potential agricultural application of remote sensing and determination of the state-of-the-art in relation thereto.	Agricultural Application of Remote Sensing--The Potential from Space Platforms
III. Narrowing the maximum range of potential agricultural applications of remote sensing from space platforms to those realistically achievable in the near future.	

Work Plan Segment	Final Report
IV. Assessment of the current state of information in each relevant application area in the various countries throughout the world.	An Evaluation of Crop and Land Use Data in a World Sample of Countries
	Worldwide Use of Airphotos in Agriculture
	Resource Management by Use of Airphotos--A Survey of Non-Federal Purchasers of ASCS Airphoto Prints
V. Potential worldwide benefits to be derived from remote sensing from space platforms.	Potential Benefits to be Derived from Applications of Remote Sensing of Agricultural, Forest, and Range Resources
VI. Priority rankings of agricultural applications	
VII. Specification of data systems	Factors and Procedures Influencing the Reliability of Agricultural Data from Earth Orbiting Sensor Systems

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Segments V and VI of this study were contracted to The Center for Aerial Photographic Studies at Cornell University and Segment VII to Systems Technology and Applied Research Corporation, Dallas, Tex. The remaining segments were done by ERS researchers, primarily in the Natural Resource Economics Division.

This summary report presents the highlights of the six major reports developed in the course of the study.

FEASIBILITY OF AGRICULTURAL APPLICATIONS OF REMOTE SENSING

At the start of the research an attempt was made (1) to identify existing agricultural applications of low-altitude remote sensing and those emerging with strong likelihood of being practicable in the near future, (2) to specify minimum imagery requirements for each potential agricultural application of remote sensing, and (3) to identify potential agricultural application of satellite observations.

The principal current application of remote sensing is aerial photography and the principal users of aerial photography are Federal agencies. Principal users in the USDA are the Agricultural Stabilization and Conservation Service (ASCS), Soil Conservation Service (SCS), Forest Service (FS), Statistical Reporting Service (SRS), and Economic Research Service (ERS). In addition, the Bureau of Land Management (BLM), and the U.S. Geological Survey (USGS), U.S. Department of the Interior, make extensive use of air photos.

Agricultural Stabilization and Conservation Service

The principal user (and producer) of aerial photography is ASCS in their production adjustment and land use programs. In these programs, designed to maintain a crop production and land use balance between supply and demand and to divert land currently not needed for production to conservation and recreational uses, the ASCS annually measures the acreage and determines the crop use of fields totaling some 200 million acres. While not all farms, fields, or crops are encompassed by the program, widely distributed crops such as corn, wheat, cotton, tobacco, and rice are included, in effect making the program nationwide in scope. For this work ASCS secures about 300,000 square miles of new aerial photography each year.

Soil Conservation Service

The SCS uses aerial photographs in major programs for the conservation and improved use of the Nation's land resources. These programs include farm conservation planning, the watershed protection program, and the soils mapping program. The agency maps the soils of some 50 million acres annually. This work requires aerial photographs which are flown with sufficient overlap to permit stereoscopic examination.

Forest Service and Bureau of Land Management

The FS and BLM are responsible for managing large acreages of federally owned land, mainly in the national forests and the public domain. In 1964, the area administered by these agencies in the 48 contiguous States totaled more than 340 million acres. Extensive portions of this land are usable for livestock grazing and are made available to private ranchers for this purpose. Both administering agencies utilize aerial photography in continuing or periodic surveys of the rangeland that is under their supervision to obtain information on its livestock-carrying capacity. Also, photo interpretation is employed to map vegetation types, terrain features forming natural boundaries or barriers to livestock movement, and water resources.

Also, the FS uses aerial photography for making forest inventories; estimating timber stand acreage; estimating the gross volume of timber, species by species, and area by area; monitoring forests for early detection of areas showing loss of tree vigor, for early detection of fires, and for improved management; planning of reforestation, recreation, and construction; and related applications. Although these tasks cannot be carried out by photo interpretation alone, they are expedited by use of aerial photography.

Statistical Reporting Service

SRS is responsible for making annual and nationwide crop and livestock surveys. It must know what is happening to yield month by month during the crop growing season. The general methods used in estimating yield are based on both mail and enumerative surveys using sampling. SRS uses aerial photographs as substitutes for conventional maps. Although only a few photographs are required, they have become a vital tool in conducting the sample surveys.

Economic Research Service

ERS uses ASCS and other aerial photography for measuring changes in land use and for appraising use potentials and conservation needs of land. Specific uses that have been made of such photography include (1) determination of the extent and rates of agricultural land deterioration, (2) estimation of land use intensity in rural floodplains, (3) delineation and evaluation of areas as potential recreation sites, (4) estimation of acreages enhanced through land clearing and drainage activities, and (5) analyses of patterns and effects of urban encroachment on agricultural lands. Stereoscopic photo interpretation with little or no fieldwork is used in ERS land use studies.

Use of aerial photographic interpretation techniques in agriculture and forestry offers advantages over ground surveys. The two especially valuable assets of aerial photography are the reasonably accurate geometry and abundant pictorial detail, which in mapping activities make unnecessary much of the preliminary task of developing horizontal control by ground traverse. The detail in aerial photography facilitates the survey by providing more orientation points than cartographic presentations. The consistency and reliability of agricultural and forestry data are often improved by using photography. Aerial photography also provides a means of obtaining timely data not available from scheduled ground surveys. The comparative photo interpretation studies of ERS yield historic land use data not otherwise obtainable. These data reveal the nature and extent of change by specific and detailed geographic areas, while traditional historical statistics show only overall net changes for relatively large areas such as counties.

Agricultural Remote Sensing Research

Current research on the application to agriculture and forestry of remote sensing in the form of multispectral; visible; near, middle and thermal infrared; as well as radar frequencies include the following potential applications:

1. Identification of crops and cropping practices
2. Plant stress analysis and yield prediction
3. Disease detection
4. Range condition appraisal
5. Identification of some soil properties
6. Soil classification
7. Measurement of soil moisture and salinity

Specification of Minimum Imagery Requirements for Each Potential Agricultural Applications of Remote Sensing

To be of maximum value as a tool for generating agricultural and related information, remote sensing data from satellites should meet certain minimum requirements. For example, satellite photographic data must provide interpretable data at an acceptable level of accuracy and consistency. Interpretation capabilities at specified resolutions are summarized as follows:

I. At a resolution of 30 meters:

Timberline

Waterline

Snowline

Desertline

Grassland-brushland interface

Brushland-timberland interface

Grassland-timberland interface

Bare soil vs. vegetated areas and individual fields 10 acres or more in size

Major roads, railroads, and waterways

II. At a resolution of 10 meters:

Mature orchard trees

Dominant rain forest trees

Fields of 1 acre or more

Farmsteads

Fence lines used to control grazing

Areas greater than 30 feet in diameter in agricultural crops damaged by disease, insects, fire, storm, or other agent

III. At a resolution of 2 meters:

Density of woody vegetation

Individual tree counts

Tree crown diameters

Species of dominant trees

Areas in agricultural crops greater than 2 meters in diameter that have been damaged by disease, insects, fire, and natural disaster

Species of continuous cover crops occupying fields greater than 20 feet square and weed patches 20 feet square

Drainage patterns

Soil series boundaries

Major soil series and soil moisture differences

Areal extent of water surfaces

Mapping of planimetric detail in agricultural areas

On sequential photography (repetitive cover of the same area), rates of plant growth, plant succession, probable future planting plans, and probable crop yields.

Potential Agricultural Applications of Satellite Observations

Based on consultation with instrumentation scientists and observation of results of experiments in progress an attempt was made to identify potential agricultural applications of remote sensing from space. Designations of (1) feasible, (2) possibly feasible, and (3) infeasible at space altitudes were applied to applications of remote sensing found to be practicable at low

Table 1. Potential applications of remote sensing from space platforms: estimated feasibility

Application area	Resolution requirements 1/		Interpretation capabilities		Estimated feasibility
	Photographic	Multispectral	Photographic	Multispectral	
Inventories of major land uses	Minimal	Minimal	Developed	Undeveloped	Feasible
Soils surveys (reconnaissance)	Minimal	Minimal	Developed	Undeveloped	Feasible
Water resources surveys	Minimal	Minimal	Developed	Undeveloped	Feasible
Bases for mapping	Minimal	Not applicable	Developed	Not applicable	Feasible
Range conditions surveys	Minimal	Minimal	Partially developed	Undeveloped 2/	Feasible
Agronomic surveys	Minimal	Minimal	Partially developed	Undeveloped 2/	Feasible
Crop species identification	Stringent	Minimal	Partially developed	Undeveloped 2/	Possibly feasible 3/
Crop vigor analysis	Minimal	Minimal	Partially developed	Undeveloped 2/	Possibly feasible 3/
Crop production estimates	Minimal	Minimal	Partially developed	Undeveloped 2/	Possibly feasible 3/
Livestock and wildlife surveys	Maximal	Maximal	Undeveloped	Undeveloped	Not feasible 4/

1/ Resolution required to obtain usable or reconnaissance-type data relative to the maximum resolution theoretically obtainable. Resolution requirements for the detailed informational objectives associated with some specific applications within broad application areas will normally be greater than those indicated.

2/ Now partially developed.

3/ Later research has shown feasibility.

4/ Later research has indicated limited feasibility.

altitudes. Essentially, application areas were regarded as feasible if the resolution requirements for usable data were not rigorous and interpretation techniques had been developed. At the other extreme, application areas were regarded as infeasible if the resolution requirements were stringent and interpretation capabilities had not been developed. The remaining application areas, where resolution capabilities appear to be adequate but interpretation capabilities have not been developed, were classified as possibly feasible (table 1).

ADEQUACY OF EXISTING CROP AND LAND USE DATA--U.S. AND FOREIGN

If the countries of the world were collecting adequate data on crop areas, crop yield, crop production, and land use, then the need for remote sensing to do these tasks would be minimal. If, on the other hand, such data are inadequate and difficult to collect, remote sensing has potential for improving and speeding up data collection.

In countries with highly developed internal and export-import markets in agricultural commodities, data on production and acreages of crops facilitate the functioning of the economies. In the developing countries, governments and private industry need data for rational and efficient development efforts. Agricultural data are a necessity under a wide variety of economic circumstances.

In carrying out the objectives of the research, 34 countries selected for study represented every continent except Antarctica. Information about land use data and the accuracy, comprehensiveness, and timeliness of available statistics on area and yields of crops in these countries was obtained from a variety of sources. Most of the reports were provided by the Foreign Regional Analysis Division, ERS. The remainder came from a number of individuals, both in and outside USDA. A standard set of questions was devised to appraise the accuracy, comprehensiveness, and timeliness of the area and yield statistics. The information, thus summarized, facilitated analysis and comparisons between countries. The land use information compiled dealt mainly with statistics on unused but potentially productive lands in the sample of countries.

Despite the lack of precise information about the data collected and the organizations responsible, it was possible to rank groups of countries as to adequacy of data. Five categories of countries were set up and each country of the sample was assigned to one of these categories or groups (table 2).

The terms "accuracy," "comprehensiveness," and "timeliness" are used as criteria for establishing the 5 groups. The terms are defined as follows:

With reference to area data:

<u>Accuracy</u>--An appraisal of procedures used in obtaining and processing data on areas devoted to various crops.

<u>Comprehensiveness</u>--The portion of the total area of country covered, and the extent of completeness of coverage within that area by the survey or census organization.

Table 2. Adequacy of Data--34 Selected Countries

Group	Description	Countries
Group I	Countries with a high degree of accuràte, comprehensive, and timely data and efficient collection organizations. Although not perfect, these organizations function smoothly and improvements would be difficult or extremely costly.	Canada Netherlands United Kingdom United States
Group II	Countries with good data collection organizations doing adequate but not intensive jobs. Data are accurate and comprehensive, but may not attain an equally high standard for timeliness. Dissemination of data may not be widespread.	Australia Denmark East Germany U.A.R. (Egypt) Romania Spain Yugoslavia
Group III	Countries making a consistent effort to collect accurate data, but having problems with comprehensiveness. Timeliness may also be deficient.	India Mexico New Zealand
Group IV	Countries with developing organizations for data collection. Accuracy, comprehensiveness, and timeliness may be lacking.	Brazil Chile Costa Rica El Salvador Ecuador Guatemala Honduras Kenya Morocco Nicaragua Paraguay Peru South Africa Syria Thailand Turkey Venezuela
Group V	Countries which collect a minimum of data and are poorly organized to do so. These countries have the least knowledge of the quantitative and locational aspects of their agriculture.	Nigeria Sudan Togo

<u>Timeliness</u>--The release of statistics by a government is considered prompt if it normally occurs within 1 month of the peak of harvest for "harvested data" or within 1 year for "revised harvested data."

With reference to yield and production data:

<u>Accuracy</u>--An evaluation of the data itself based on the methods for gathering and processing it.

<u>Comprehensiveness</u>--Appraisal of the completeness of crop enumeration in relation to the means by which data are obtained.

<u>Timeliness</u>--The estimates released by a government are considered prompt for "forecast" if they are made prior to the harvest and are based on evidence not more than 1 month old; they are prompt for "harvested" if they are made within 3 months after harvest.

Of the 34 countries studied, 23 were lacking in the accuracy, comprehensiveness, or timeliness of the crop area, yield, and production data they collect. These were those assigned to Groups III, IV, and V, and most can be described as underdeveloped or developing countries. Many are under pressure to produce more food for increasing populations and are developing and implementing comprehensive national plans. To formulate an effective plan, however, it is necessary to understand conditions as they really are. In agriculture, information is needed on yields and production of crops as well as location and acreage.

Speed and repetitive coverage of large areas are inherent characteristics of satellite remote sensing systems. Remote sensing will not provide an improved source for all of the economic data now collected, but it can improve crop area, production, and yield data collection and make these operations more efficient.

Good land use data and maps were lacking in most of the 34 countries. Land use data are frequently byproducts of the collection of other agricultural data. Thus, lands outside of those devoted to agriculture are usually unaccounted for. The high cost of collecting data and mapping land use has, in most countries, hindered such efforts. A few countries, such as the United Kingdom, Netherlands, and Canada have systematic programs of land use data collection and mapping. The Food and Agriculture Organization and the International Geographical Union have attempted to collect new data, organize existing data, and plan for future land use mapping on a world scale, but these efforts have had only limited success.

There is a growing need for comprehensive land use data collection and mapping because of increasing human pressure on land resources. Even in the economically more advanced countries where most of the available agricultural land has been occupied, it is becoming apparent that better land use information is needed. These countries desire to know more fully the extent and location of their agriculturally productive lands as well as their forest, urban areas, transportation networks, recreation areas, wastelands, and changes in use that are taking place. Population pressures are causing many countries to analyze their needs and plan the use of land for future populations. The foundation for such planning is accurate land use information on present conditions.

The developing countries also face the problem of growing populations. Food production for the near future is their great problem. In this situation, these countries have turned to planning as a solution. The early phases of such planning require accurate appraisals of agricultural production. Land use mapping and data collection enable the identification and inventory of productive areas, potentially productive areas, and wastelands. This is a necessary first step.

Of great interest to developing countries is the identification of their most promising unused lands having potential for future development. Land use maps accounting for the total surface of the country show the location of unused or lightly used areas. It is here that the potential is to be found. Sorting out areas with agricultural potential from wastelands requires research and the mapping of soils, rainfall, slope, and other factors. Remote sensors can eventually provide much of this detailed information, but one of the first tasks of the sensors will be to identify and map unused areas.

Much work in land use mapping and identification of potentially productive areas will probably fall to remote sensing systems by default. Little is being accomplished currently by traditional survey techniques. The need for this type of information will grow and with it the demand for low cost techniques to quickly cover large areas of the earth's surface. Airborne and satellite-borne remote sensor systems can do much to fill this need.

WORLDWIDE USE OF AIRPHOTOS IN AGRICULTURE

Assessing world-wide potential economic benefits of agricultural resource surveys from earth orbiting satellites requires knowledge of the scope and extent of the current utilization of conventional aerial photographic techniques for data acquisition. A sample of 33 countries 1/ was selected for this assessment and the usefulness of conventional aerial photographic surveys was evaluated as a technique for acquiring data on land use and crop production, identification of potentially arable land, and measurement of other agricultural parameters.

Following World War II, the experience gained in the use of stereo interpretation of airphotos in military intelligence was applied to agricultural data collection in many parts of the world. In the countries studied, airphotos have been used primarily to provide data on major land use and as an aid in agricultural inventories, and as general purpose maps.

Methods for procurement of imagery varied somewhat in the sample countries. In the past, coverage was usually taken by a military or government agency,

1/ Australia, Brazil, Canada, Chile, Costa Rica, Denmark, East Germany, Ecuador, El Salvador, Guatemala, Honduras, India, Kenya, Mexico, Morocco, Netherlands, New Zealand, Nicaragua, Nigeria, Paraguay, Peru, Romania, South Africa, Spain, Sudan, Thailand, Togo, Turkey, U.A.R. (Egypt), United Kingdom, United States, Venezuela and Yugoslavia.

Table 3. Airphoto coverage of existing and potential agricultural and range areas

Country	Percentage of coverage			Approximate dates of coverage	Remarks
	Small scale	Medium scale	Large scale		
Australia	100	Partial	Partial	Largely before 1950	
Brazil	100	Partial	Partial	1942-62	
Canada	100	100	Partial	1940-66	
Chile	100	Partial	Partial	1945-63	
Costa Rica	100	-	-	1947	
Denmark	-	100	-	1956	
East Germany	-	Partial	-	Post WW II period	
Ecuador	Partial	Partial	-	1940-63	1:60,000 coverage being flown
El Salvador	100	Partial	Partial	1949-63	
Guatemala	100	Partial	-	1952-64	
Honduras	85	Partial	Partial	1954-63	
India	Partial	Partial	Partial	1939-65	
Kenya	Partial	Partial	-	1963	U. N. Special Fund Project
Mexico	100	Partial	Partial	1940-57	
Morocco	100	-	-	Post WW II period	
Netherlands	-	100	Partial	1934-50	
New Zealand	100	Partial	Partial	Largely before 1950	
Nicaragua	Partial	Partial	Partial	1946-64	
Nigeria	Partial	Partial	-	1962	U. N. Special Fund Project
Paraguay	100	-	Partial	1940-64	
Peru	Partial	Partial	Partial	1941-63	
	-	Partial	-	Post WW II period	
South Africa	90	Partial	Partial	1940-59	
Spain	-	Partial	-	Largely after 1941	
Sudan	100	Partial	-	1942-62	Recent coverage for U. N. Special Fund Project
Thailand	Partial	Partial	-	1956-57	
Togo	-	100	-	1962	U. N. Special Fund Project
Turkey	-	Partial	-	1964	U. N. Special Fund Project
U.A.R. (Egypt)	100	100	Partial	1953	
United Kingdom	Partial	100	Partial	1945-56	
United States	Partial	95	Partial	1936-65	
Venezuela	Partial	Partial	Partial	1936-64	
Yugoslavia	-	Partial	Partial	1949-55	

especially for small-scale mapping photography. Recently the trend in most countries is toward obtaining imagery by contract with private companies. Generally, this coverage is obtained on a project or regional basis for carrying out inventory and planning for development of natural resources. Several countries have a coordinating organization to review needs for imagery and to promote multipurpose use of coverage by all government agencies.

In many of the less developed countries the use of airphotos in agriculture is just beginning and such use will undoubtedly increase in the future. One of the primary uses of airphotos in these countries has been as a base for planning for agricultural development. The photos provide survey data to show distribution and pattern of existing land use and serve as base maps for soil classification. Their use has accelerated field surveys and increased the timeliness and accuracy of data gathering.

Use of airphotos in agriculture in the countries studied varies from very limited in some to extensive in others. In less developed countries, airphotos are used to obtain survey type resource information needed for planning. In more developed countries, airphotos provide an economical means of getting up-to-date information on land use changes; for checking farmers' compliance with government programs; and in soil conservation, forestry management, resettlement and development, and watershed programs. In many of the less developed countries, a wider use of airphotos is hampered by unawareness of their capability for providing useful data and by a shortage of personnel trained in airphoto analysis techniques.

Photography available in most countries is small-scale because it was obtained primarily for preparation of maps. Scale often varies widely and coverage is spotty. Airphotos are sometimes restricted to military use and are not available to civilian agencies.

Airphoto coverage for the sample of countries studied is shown in table 3. Many have only recently acquired airphoto coverage suitable for use in agricultural inventorying and planning.

In the countries where UN Special Fund projects are in operation, scientists are using airphotos to conduct needed surveys and at the same time are training local personnel in the techniques of airphoto analysis. As more nations acquire usable airphoto coverage, the need for personnel trained in photo interpretation and analysis will become more critical.

The main areas of application and subject matter fields for airphoto use are presented in table 4. Use of airphotos in agriculture is increasing throughout the world, and will probably continue to increase in the future. This is especially true for the larger countries where problems of obtaining data over wide areas are acute and for the less developed areas where time is a critical factor in getting agricultural development underway.

AIR PHOTO USE IN THE UNITED STATES

Because of the likelihood that future photographs from space may be substituted for or used in conjunction with conventional aerial photographs,

Table 4. Major uses of airphotos in agriculture, by subject matter 1/ and by country, world sample

Country	Major application																																		
	Survey base												Airphoto interpretation																Program base						
	A	B	C	D	E	F	G	H	L	M	N	O	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
Australia	x	x	x	-	x	x	-	-	x	-	-	-	x	x	x	-	x	-	-	-	-	-	-	x	-	-	-	-	-	-	-	x	-	-	-
Brazil	x	x	x	-	x	-	-	-	-	-	-	-	x	x	x	-	x	-	-	-	-	-	-	x	-	-	-	-	-	-	-	x	-	-	-
Canada	x	x	x	x	x	-	x	-	-	-	-	-	x	x	x	x	x	-	x	-	-	-	-	-	-	-	-	-	x	-	-	x	-	-	-
Chile	x	x	x	-	-	-	-	-	-	-	-	-	x	x	x	-	-	-	-	x	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-
Costa Rica	-	-	x	x	-	-	-	-	-	-	-	-	-	-	x	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-
Denmark	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
East Germany	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ecuador	x	x	x	-	x	-	-	-	-	x	-	-	x	x	x	-	x	-	-	-	-	-	-	-	x	-	-	-	-	-	-	x	-	-	-
El Salvador	x	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Guatemala	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Honduras	x	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
India	x	-	x	-	-	-	-	-	-	-	-	-	x	-	x	-	x	-	x	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-
Kenya	x	x	x	-	-	-	-	-	-	-	-	-	x	x	x	-	-	-	-	-	-	-	-	x	-	-	-	-	-	x	x	-	-	-	-
Mexico	x	x	x	-	-	-	-	-	-	-	-	-	x	x	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-
Morocco	x	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Netherlands	x	x	x	x	-	-	-	-	-	x	-	-	x	x	x	x	-	-	-	-	-	-	-	-	x	-	-	-	-	-	x	-	-	-	x
New Zealand	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	x	-	-	-	-	-	x
Nicaragua	x	x	x	-	-	x	-	-	-	-	-	-	x	x	x	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nigeria	x	x	x	-	-	x	-	-	-	-	-	-	x	x	x	-	-	-	x	-	-	x	-	-	-	-	-	-	x	-	-	x	-	-	-
Paraguay	x	x	x	-	-	-	-	-	-	-	-	-	x	x	x	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-	x	-	-	-
Peru	x	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rumania	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	x
South Africa	x	x	x	-	-	x	x	-	-	-	-	-	x	x	x	-	-	x	-	-	-	-	-	-	-	-	-	-	x	-	-	x	-	-	-
Spain																																			
Sudan	x	x	x	-	-	-	-	-	x	-	-	-	x	x	x	-	-	-	-	-	-	-	-	x	-	-	-	-	-	x	-	-	-	-	-
Thailand	x	-	x	-	-	-	-	-	-	-	-	-	x	x	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Togo	x	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Turkey	-	-	x	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
U.A.R. (Egypt)	x	x	x	-	-	-	-	-	-	-	-	-	x	x	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
United Kingdom	x	x	x	-	x	-	-	-	-	-	-	-	x	x	x	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
United States	x	x	x	x	x	x	x	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	-	-	x	x
Venezuela	x	-	-	-	x	-	-	-	-	-	-	-	x	--	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Yugoslavia	x	x	x	-	-	-	-	-	-	-	-	-	x	x	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

1/ Letters in boxheads stand for subject matter as follows:

A. Soil classification
B. Land use capability
C. Land use classification
D. Land use change studies
E. Natural vegetation
F. Livestock and range survey
G. Soil erosion survey
H. Crop identification
I. Crop estimates
J. Crop disease detection
K. Flood control survey
L. Water development
M. Watershed and hydrologic studies
N. Recreation site evaluation
O. Wildlife habitat studies
P. Wildlife inventory and management
Q. Soil conservation program
R. Irrigation program
S. Soil drainage program
T. Agricultural colonization program
U. Agrarian reform program
V. Crop acreage control program
W. Reclamation programs

a survey was made of the uses currently being made of conventional airphotos in the U.S. This survey was designed to determine the nature and extent of the non-Federal use of airphotos purchased from the ASCS. The ASCS maintains airphoto coverage of all of the Nation's farmland as an aid in administering Federal programs. There are no photos for some northeast forest areas and some western forest and desert areas. ASCS supplies airphotos to other government agencies and to the public at approximate cost. Non-Federal customers in fiscal year 1966 placed 40,141 orders for 470,984 airphotos of various sizes, or 40 percent of ASCS total output. The file of order forms provided the mailing list and universe for this sample survey. About 10 percent of the orders were for 15 or more prints ("large orders") and accounted for three-fourths of the prints sold. This "large order" group was sampled at a higher rate than the remaining "small order" group (less than 15 prints) which accounted for 90 percent of the orders, but only one-fourth of the airphotos purchased. The number of questionnaires tabulated represented 20 percent of the "large order" group and 2 percent of the "small order" group. In terms of total purchases for fiscal year 1966, the sample accounted for 59 percent of the total fiscal year 1966 non-Federal sales.

Of the total production of 1,156,880 photoprints in fiscal year 1966, ASCS distributed about a seventh (157,118) to their own offices for use in adminisering farm programs. Most agricultural counties have a county ASCS office, usually in the county seat, where airphoto coverage for the county is on file and available to the public for viewing. While prints are not available for sale at the county offices, assistance is provided in ordering from the ASCS photolabs.

Other Federal agencies also use a large number of prints in carrying out their respective responsibilities. In fiscal 1966 these agencies acquired 528,778 photoprints, or 46 percent of the total ASCS output. Major customers included FS, SCS, Department of Interior, Department of Commerce, and Department of Defense.

Most non-Federal orders--almost-three-fourths--were from business users. Non-Federal governmental units (State and local) accounted for 5,232 orders, or about an eighth of the total. Big users in this category were State agencies such as conservation, forestry and highway departments; and local units such as counties for assessment and planning work. Educational and research agencies and institutions accounted for 1,790 orders or 4 percent of the fiscal year 1966 total. Photoprints for personal use accounted for 3,534 orders or 9 percent of the total. A few orders were received from groups such as local conservation societies and boys' clubs.

Types of Business Customers

The uses to which airphotos will be put is indicated to some degree by the type of business that orders prints. Agriculture, petroleum and minerals, real estate and utilities accounted for 83 percent of the total 29,034 orders received from business (table 5).

Farms and ranches led in number of orders, accounting for 40 percent of the total business orders, but most orders were placed for only one or two prints.

Table 5. Business users--number of orders by type of business

Type of Business	Orders for air-photos (number)
Photogrammetry and photo interpretation	21
Aerial surveys	11
Map service	238
Agriculture: Farming and ranching	11,726
Crop dusting	217
Forestry and forest products	2,279
Minerals: Geologic consultant	187
Photogeology	73
Geologic exploration	858
Petroleum and gas production	772
Drilling contractor	6
Mining	182
Coal	21
Aggregate (sand and gravel)	94
Land use planning (city, region)	311
Real estate: Real estate development	552
Industrial development	158
Real estate sales	3,552
Construction: Engineering and architecture	2,682
Construction	15
Utilities: Multiple	42
Electric	196
Water	9
Gas	41
Pipeline	76
Telephone	30
Railroad	47
Recreation	364
Other: Surveying	506
Real estate appraisal	544
Tax appraisal surveys	14
Banks, insurance companies	403
Attorneys	1,300
Land management consultant	9
Traffic consultant	6
Chamber of Commerce, civic org.	254
Manufacturing plant	402
Retail merchant	20
Miscellaneous	818
Total Orders	29,034

The private forest industry with 2,279 orders accounted for 8 percent of the total, with many large orders. In addition, large numbers of airphotos are used by State and local government units for forest management.

Mineral and petroleum oriented industries accounted for 2,193 orders or 8 percent of the total. In this group most orders were from oil and gas industries, particularly the sectors concerned with exploration. Many of these were large orders for extensive airphoto coverage. An appreciable number of orders (297), however, were received from mining and sand and gravel businesses.

In the real estate category, most orders were from sales agencies, but many came from real estate and industrial development groups. The closely related category of land use planners accounted for 311 orders, or about 1 percent of the total business orders. Real estate in total (planning, development and sales) accounted for 16 percent of total orders. Most of these orders, however, were relatively small, often for coverage only of a single tract or farm.

The construction industry, including architecture and engineering, accounted for 9 percent of the total orders. The types of business ranged from those engaged in local projects requiring only a few photoprints to highway construction firms requiring extensive coverage. Businesses related to real estate and construction, such as surveyors, appraisers, and loan departments of banks and insurance companies each accounted for about 1 percent of airphoto orders by business organizations.

Utility companies accounted for relatively few orders (2 percent) but orders were generally for large numbers of prints. Almost half of the utility orders were from electric companies while the remainder came from gas, telephone, railroad and pipeline companies.

Attorneys also were frequent purchasers, accounting for 1,300 orders or more than 4 percent of the total for business. These orders were usually small with coverage of specific local situations. Other types of business customers included chambers of commerce, civic organizations, manufacturing plants, retail merchants, traffic consultants and map services. A few orders were received from private aerial survey companies as well as from professional photogrammetrists and photo interpreters.

Contact prints (9 1/2" x 9 1/2-3.2 inches per mile) were by far the most common size purchased from ASCS, accounting for two-thirds of the 470,984 prints ordered by non-Federal customers. The most common enlargement was the 26" print (8 inches per mile) accounting for 14 percent of the total sales. The 14" and 18" sizes accounted for 12 percent of the total, while the 40" enlargement (13.2 inches per mile) and the photo index sheet (1 inch per mile composites of contact prints) each came to only 4 percent of the total sales.

The business group showed interest in a broad range of sizes, reflecting their varied needs. The forest industry with interest in more efficient management, the utility industry with its major interest in "rights-of-way" and the mineral industry with major interest in geologic exploration favored the contact prints. The real estate industry, using the photos for development and sales purposes, and agriculture for field measurement and recordkeeping purposes favored the enlargements. Hence, contact prints accounted for only 54 percent of purchases by the business group; enlargements accounted for most of the remainder. Photo index sheets accounted for 5 percent of business purchases.

State and local government units with a major interest in public land management, land records, and tax problems generally preferred contact prints, which accounted for 75 percent of their purchases. Some enlargements, however, were ordered for use in development and planning and other problems associated particularly with urban development. This group ordered relatively few photo index sheets.

For education and research work the contact prints were by far the most popular. Professional photogrammetrists and photo interpreters, who are in this group, purchased contact prints primarily because of the need for stereo viewing and various magnifications. In some research work (geologic or archeologic investigations) broad coverage consistent with a workable scale is preferred over enlargements. Some extensive land features are sometimes even more evident on the smaller scale photo index sheets. Six percent of the prints ordered by this group were photo index sheets, the highest proportion in any group.

Resolution

ASCS photography is taken and developed in a 9 1/2" x 9 1/2" film format at a scale of 3.2 inches per mile. Enlargements are available up to 40" x 40" or a scale of 13.2 inches per mile, but detail at this scale becomes somewhat fuzzy. Ground resolution on the contact prints is 2 to 3 feet. More than two-thirds of the customers were satisfied with the contact print's degree of visual detail for their various objectives, with little difference in this proportion among the user groups. Of those who desire a different degree of detail, most preferred a film scale which would yield greater detail. This was particularly true of realtors, appraisers, and city land planners. Only 2 percent of the customers preferred greater coverage with less detail, that is, more synoptic imagery.

Those in the business group who desire better "ground resolution" included real estate people (appraisal and boundary determination) farmers and foresters (measurement and ground cover identification), engineers (detailed terrain analysis), and city planners who wished relatively detailed data on dwellings by type. In government the desire for greater detail was reported by highway engineers, city planners, tax appraisers, foresters, and zoners. Professionals in education and research indicated a desire for greater detail for instructiona purposes and for such projects as beach erosion studies, land cover studies, and soils mapping.

New ASCS Airphoto Coverage

To keep ASCS airphoto coverage up-to-date for the intended purpose, new photo coverage is acquired about every 5 to 8 years. This varies depending upon the proportion of land in cropland and upon the rate of the shifting of land in or out of crop production and changes in land patterns. Hence, the age of the photography currently on hand ranges from less than 1 year up to 7 or more years. The average age of current photography is probably 3 or more years. For many purposes, such as investigations of the rapidly changing rural-urban interfaces and new highway complexes, this limits severely the usefulness of the photos.

Almost 40 percent of all the customers queried felt that more recent photo coverage would be "much more" valuable in their work. Although the proportion was about the same in the overall business group, 53 percent of businesses placing large orders (15 or more prints) felt that more recent coverage would be much more valuable. This large order business group accounted for 45 percent of the total number of airphotos purchased by non-Federal buyers in FY 1966. Foresters mentioned the need for current photos, particularly for mensuration estimates but also for reseeding plans and property line determinations. Utilities need current photos for "long line" planning but more importantly for distribution line planning and construction in areas of new development. Real estate people in development and sales and appraisers also indicated the importance of current coverage. Others who preferred newer airphotos included planners (both city and regional), market researchers, engineers, and mapmakers.

Economic Benefits

Customer opinion of economic benefits received from ASCS airphotos ranged from none (12 percent) to substantial (41 percent). Only 29 percent reported benefits as only slight or none. This group included a large number of those in education and research who reported no direct monetary returns, and farmers who made only occasional use of their photographs for recordkeeping or field measurement. The large order (15 or more prints) group of business customers reported considerable airphoto value. More than half of this group stated economic benefits were substantial, while a third reported moderate benefits.

ECONOMIC POTENTIAL FOR AGRICULTURAL, FOREST, AND RANGE APPLICATIONS OF REMOTE SENSING

The justification for obtaining information by remote sensing lies in the unique advantages over other means and gains in information acquisition thereby made possible. The practical values to result from remote sensing, however, depend upon the values of the uses to which the information is actually put.

This segment of the research explores the uses and associated values of the information that could potentially be provided by remote sensing from low and high-altitude aircraft and from satellites. Supporting material, comprising technical and economic analyses of these uses (or applications), stemmed from a detailed and critical evaluation of remote sensors and of the agricultural, forest, and range resources to which they may be applied. The objective was to indicate the magnitude of the potential values that could be derived from remote sensing of these resources.

Remote sensing includes any means of gaining information without direct contact. It can, therefore, refer to information-gathering processes involving distances from the object of interest of a few inches or feet to a few miles or even hundreds of miles. Primary emphasis has been placed on applications from distances associated with space vehicles and airplane operations, even though some applications of great potential value can be carried out on the ground. Remote sensing in general can provide information with unique and valuable characteristics--unbiased and accurate information, in real-time (or very nearly so), in volumes never attainable before, and in useful format.

Applications were considered in terms of what most likely will be feasible at some later date, approximately 1975. Progress in the remote sensor field is so rapid that even within the time of this study several new capabilities were identified.

Having eliminated sensor capability as a major restriction, the approach was to look at all activities within agriculture from the point of view of the farmer, rancher, forester, and professional agriculturist and to ask what information is or would be of value to the individual making decisions. Information is the basic product of remote sensing and its major use is in making decisions. In agriculture, decisions are made at several levels--by the U.S. Department of Agriculture; by State and local government officials; by fertilizer, seed, machinery, processor, marketing and transportation personnel; and by individual farmers. Each level needs to be considered.

Varied sources were used to determine the several hundred ways in which agriculture could use information. Project staff knowledge was combined with discussions with farmers, food processors, and other agricultural industry personnel to assess requirements for knowledge in operational decisions. Interviews with government administrators and agency officials provided the background for understanding information requirements for governmental policy decisions. Basic text books on ecology, plant breeding, silviculture, forestry, conservation, range management, agronomy, plant pathology, entomology, agricultural marketing, and animal husbandry, were used to identify areas of desired information. Government publications and contractor reports concerning remote sensing and possible agricultural applications were examined. Technical papers, journals, and research reports were also used.

From these many sources, hundreds of ideas were developed on how information could be used in agriculture. These were then further evaluated and those with low potential were eliminated. The feasibility of each application listed in tables 6, 7, and 8 has been confirmed by one or more persons directly associated with the field involved.

The possibilities for applications are so varied and cover such a wide range of agricultural activities that no claim is made relative to the completeness of these listings. It is believed that no major applications have been overlooked but there are certain to be new applications suggested that have not been listed.

It is clear that levels of interpretation of information can have major effect on the magnitude of benefits. Automatic sensing and recording of data based on automatic, discreet selectivity of key subject signatures amounts to census taking, and is what might be termed "first degree interpretation"--that process of identifying an object or item and simply adding up the area or volume involved. This offers many opportunities to provide information costs now precluded because of cost. Any reduction in the cost of obtaining raw data increases the number of economically feasible applications, thereby increasing the potential for greater benefits.

However, more benefits will be derived with more intensive interpretation. Analysis and inferential interpretation for use in policy, planning, development and other types of decision-making will enable full realization of benefits from remote sensing. Automatically tallied census information will be a beneficial adjunct to these higher forms of use, but will not accomplish the complete, successful use of remote sensing. Accomplishing this requires that all levels of interpretation be used to realize the potential of the information made available by remote sensing.

Agricultural Applications of Remote Sensing

Applications of remote sensing for agricultural use cover the widest range of the three major areas studied (agricultural, forestry, and range). They vary from intensive use at low altitudes to extensive or continental mapping of resources from satellites.

The unique characteristics of agricultural applications--as distinct from range or forestry applications--require that certain specific considerations be made. For example, (1) the number of people involved is far greater; (2) the land and capital managed by the individual farmer are usually much smaller; and (3) the farmer, due to the smaller size of area involved, has a more intimate knowledge of his local situation than is possible in forestry or range management. If an application is to be of any value, it must either improve upon information that the farmer can gather from frequent inspections of his small land area or give him useful information not now available.

Problems of communicating remotely sensed information to the farmer, as ultimate user, are complex because of the great numbers involved. Realizing potential benefits from a remote sensing operation depends on whether decision makers take any action as a result of the new or improved information. Attempting to estimate the degree of response in the U.S. is extremely difficult and is virtually impossible on a world-wide basis.

There appear to be three broad classes of countries to be considered in terms of economic and technical levels of agricultural development, and varying degrees of value will accrue to the use of remote sensing in each class. Among countries with highly developed agricultural technology, with high levels of employment, and where major advances in the efficiency of agricultural production continue to keep pace and balance with economic development, we can expect high rates of use and significant rewards from remote sensing.

At the other extreme are countries struggling to make major strides in their agricultural and economic development. They are aware of the need to take advantage of all possible technical development to increase their rate of improvement. In spite of labor surpluses and little capital, they are receptive to the possibilities new tools offer and will probably also utilize remotely sensed data.

The third group comprises the countries that show little or no interest in or concern for major advances in agricultural development or whose resources would not respond to technological change. Many of the economically stable countries fall in this third category along with the undeveloped countries that have a stabilized economic activity at a low level. It is therefore equally difficult to envision that the results of remote sensing will have any significant effect on the management decisions of dairy farmers in the Alps or nomads in Africa.

Because of this the estimated values for world-wide use of certain applications are offered only as an indication of the magnitude of the possible benefits. Estimated values were often developed by extrapolating to a world-wide basis such per-unit figures as were available. Considering the variability and questioned accuracy of world-wide figures for almost any form of agricultural information, these estimates are not vigorously defended. The basic area figures were taken from the annual USDA publication, "Agricultural Statistics," from FAO "Production Yearbooks," and from other FAO publications.

There is almost no research relating benefits directly to remote sensing. Consequently the approach has been to use techniques such as those employed in farm management surveys to determine what information could be of value. By doing this, some highly publicized applications lost importance while other applications were pointed up. The sensing of diseases of grain crops is a good case in point. In the U.S., farmers rarely treat a grain crop for disease control--control measures are lacking or too expensive. Therefore, at the present time, knowledge that a rust is infecting farmer Y's wheat field would not result in benefits to that field attributable to remote sensing, since farmer Y does not make any attempt to control rust.

The usefulness of this knowledge is not in on-farm decisions. It becomes useful on a more aggregative basis as a means for predicting yields, indicating spread of disease, selecting disease-free seed stock, and indicating areas that may be producing disease-free or disease-resistant strains of wheat.

The available literature on remote sensor applications to agriculture could not be used directly in developing lists of uses. Much of it pertains to specific technical qualities of individual sensors. Much is primarily concerned with research problems or techniques.

The timing of coverage for agriculture was found to be less important than had been thought previously. Complete coverage of the U.S. or the world in one short time-span will rarely be needed. For most applications we will be looking at certain features under specific conditions. There will be no need to measure snow depth except at certain times during the pre-run-off period. There is no point in covering all the eastern United States in determining the extent of frost damage to the Florida citrus crop. There are few uses that are not related to specific seasonality, activity, or need for knowledge.

In this respect, the prospects for using high-altitude aircraft coverage are very inviting. Most of the world's annual food supply is planted, grown, harvested, and stored or consumed in less than 6 months. Tracing the development and migration of potato blight along the eastern U.S. seaboard, for example, may require information as frequently as every 3 to 5 days, depending on wind, moisture, and temperature conditions. The ultimate in continuous information would be synchronous orbiting satellites. Short of that, high frequency of availability of satellite coverage would be helpful, but the efficiency of high-altitude aircraft should be thoroughly analyzed first. Because of their mobility, they may well prove to be the most efficient source of acquisition of remotely sensed information for some applications. Probably planes and satellites will be used for complementary roles in joint programs.

Some crops are so intensively managed that it is doubtful that remote sensing from air or spacecraft will be of much value. In these cases, short-range sensors might give the farmer "on the farm" pre-visual information about plant conditions. Intensive crops, especially those for fresh market consumption, require preventive care in the control of insects and disease. To inform farmers after their crops have a disease might be of little value, but monitoring the spread of disease or insects may permit preventive care measures on crops not yet affected.

Caution is needed in evaluating the use of remote sensing information to generate changes in the market. Short range rewards to market operators might be generated, but these are not the same as direct benefits to the farmer. Also, in the long run the positive and negative market responses will usually off-set each other.

There are many instances of secondary and tertiary benefits that could logically be claimed. These were not generally included. In one instance it was possible to obtain a rough estimate of benefits to the canning industry, which would result from better timing of crops, better knowledge of irrigation needs at the farm, etc. Other industries also would benefit, and in like manner we could claim that better production leads to more capital investment, which leads to more taxable real estate, which leads to a better school system, which leads to a higher education level, etc. This circle of events was not included as part of the benefits assigned to remote sensing in agriculture.

There are additional problems in deciding whether remotely sensed information is necessarily better. In some cases it would be difficult to improve on the low-cost methods used to gather useful data. For example, the inexpensive postcard reporting system used by the Statistical Reporting Service may well continue to be used even with the implementation of remote sensing.

An important point to consider is that it will be necessary to develop an outstanding, accurate, and fast information service to get the information to the farmers or other decision makers. Merely gathering volumes of data has no value. Processes for retrieval and dissemination of information must be developed.

The work presented here does not attempt to consider the cost of developing and operating services that will solve these problems. Instead, the uses are identified and an estimate based on the best information or advice available is given for the gross value of each application, in terms of either the value of the product or the lower cost of gathering information. (Table 6)

Forestry Applications of Remote Sensing

Many forestry applications of remote sensing are already operational. This is due in part to the fact that because of the great areas involved, much of the information needed about forests is too expensive to obtain by surface techniques.

In forestry applications benefits are not as great on a square mile or annual basis as they are in range management or agriculture. The harvest cycle ranges from 25 to 30 years in the rapid growth areas to over 100 years for certain species. Because of this, most forest applications have usefulness on an infrequent basis, with certain specific exceptions such as fire, disease, and insect control applications. For much of the United States and the rest of the world, mapping and inventory will not be needed more often than every 10 to 20 years. For some applications, areas must be covered annually and coverage on an hourly basis or less may be necessary for forest fire surveillance.

The range of applications in forestry is as broad as in any of the other areas of application--the delineation of forest areas of the world represents one extreme, while detailed knowledge about individual trees represents another.

At present a comprehensive and adequate inventory of the world's forest is not readily available. No reliable maps exist for much of the forested areas of the world. Thus, the mapping of the world's forest areas becomes one of the major forestry applications. Detailed inventories next become significant with quantity and quality evaluations the major information derivable. As progressively smaller areas are considered, additional inventories can be carried out, management practices enhanced, and more localized planning activities relating to forestry become feasible.

The total range of applications considered was broader than the range of activities of the Forest Service and other government agencies. Included are such diverse activities as forest fire control, recreational use of forest lands, and information desired for policy decisions. The one basic requirement was that the application be beneficial. Thus, fire is treated both as a beneficial tool and as a destructive hazard to be prevented.

Three basic sources of ideas for applications of remote sensing in forestry were used: (1) governmental reports; (2) basic textbooks used by professional foresters and academic institutions, and (3) interviews and conversations with experienced foresters, researchers, and administrators. Available reports provided the background necessary to determine the kinds of information now considered useful and, by tracing certain activities through the appropriate budget reports, the amount spent to obtain the information.

Range Land Applications of Remote Sensing

The management of range land combines qualities of both a science and an art in the process of obtaining maximum yields while conserving range resources. Range management does not have the same opportunity as does farming to develop, or to change the character of, the natural resources employed. Rather, range management is directed toward maximizing production from the innate productive capacity of the range resources, much as in forest management. Also, unlike agriculture, range land must be considered in large management units, often thousands of acres in size. This creates unique information requirements, involving patterns of relative differences instead of accurately measured differences.

A basic consideration in range management is the existing ecology of the range. Range management, with the use of ecological knowledge, can accelerate or retard the rate of biological transition in a manner allowing advantageous use of the plant production of the range over long periods of time. Danger always exists that range will deteriorate to some "point of no return." Accordingly, range management is continually concerned about the "trend in condition" of the range resources.

The requirements for information are varied. Detailed ecological analysis requires sampling the plant population on the basis of very small units, such as a few square yards. Yet at the other extreme, knowledge of plant, disaster, and livestock conditions are required for thousands of acres. Remote sensing has potential for extrapolating over large areas to develop information prohibitively expensive by conventional methods.

It has been estimated that technology is available for increasing production from existing U.S. range resources by 70 to 100 percent. Of this increase, most could come from better range operation with the remainder from improved stock and breeding. Remote sensing can play a major part in generating the increase in production by better range management. In many other parts of the world, the opportunity for increases due to improved management of range land is several times that of the U.S.

Demand outlook for meat is favorable. The American Meat Institute has indicated that the demand, especially for beef products, is increasing much more rapidly than the supply. The increased demand is basically from two sources --increased population and increased individual purchase of beef products as a society becomes more affluent.

In many situations the production of wildlife resembles range management. The demand for wildlife has also shown pronounced increases in recent years. Professional wildlife managers estimate that 20 to 30 percent more wildlife could be harvested solely with better information for management.

Range applications of remote sensing are considered in terms of their applicability to policy, management, physical development, and disasters. There are many examples of how information alone can become a major source of increased income to ranchers. A prime example is the use of remote sensing to monitor the carrying capacity of range land. Currently accepted management practices call for stocking at only 85 percent of carrying capacity. With better knowledge of range conditions, the range might be stocked to 95 percent. Such an improvement would amount to an annual increased value of production of hundreds of millions of dollars.

Other applications would involve mitigation of disasters afflicting range land and its flora and fauna, e.g., floods, fires, wind, erosion, wild and human predators, insects, diseases, and a wide variation of adverse climatic conditions.

Other useful information would be the location and management of water in range areas. In many areas stock water is the limiting resource.

The heat sensors have potential for such uses as census taking, locating diseased stock, identifying unique forage areas, and assisting in roundups.

Of the three major areas of application, range management might easily benefit the most, mainly because there is so much room for improvement and because the management of range land is so dependent upon timely information. The total value of benefits will be greater for crop applications, but some range applications may be operational earlier.

Applications

The tables 6, 7, and 8 present lists of selected applications for which there appears to be a financial return. 1/ Many other applications were considered but did not show sufficient promise of benefits to warrant attempts at further analysis.

The tables indicate whether the application was suggested from activities already carried out, from management or research people, or from personnel working on the project. The second column generally indicates at least one USDA agency that would be expected to be concerned with the particular application considered. In many cases there are other agencies that have, or will develop, an interest in the application.

The dollar estimates are based on anticipated annual gross returns to resources through both savings and improvements. Whenever possible, the estimates are supported by published data of various agencies of the USDA. Other sources also were used. Estimates of dollar benefits have not been attempted for a number of the applications because it was not possible to find any basis for such estimates. In many other instances the estimates are based on judgments of staff members. The benefits listed for applications on a world basis have been held to low levels because of the uncertainty of their being carried out and the lack of supporting figures. In most cases the world benefits are based on data similar to those used for the U.S.

Estimates were developed generally on the basis of the following assumptions:

1. That any current information procurement and dissemination activity is worth the cost incurred.

2. That information obtained from remote sensing will be used.

1/ Tables 6, 7, and 8 are taken from Potential Benefits to be Derived from Application of Remote Sensing of Agricultural, Forest, and Range Resources. (Unpublished). Center for Aerial Photographic Studies, Cornell University. Dec. 1967.

Table 6. Agricultural Applications

Applications	Source of estimates 1/	Interested USDA agency 2/	Annual U.S. benefits 3/	Annual world benefits 3/
			(Million dollars)	(Million dollars)
1. Flood control planning	H	SCS ERS	*	*
2. Flood damage evaluation	H	SCS ASCS FCIC	*	*
3. Evaluation of storm damages	P	ASCS FCIC	30	120
4. Drought prediction systems	P	ARS	200	600
5. Air pollution control	H	ARS	500	1,000
6. Epidemic analysis and mapping	P&H	ARS	500	1,500
7. Control of wildlife habitat	P	-	10	*
8. Weed control	H	ARS	885	2,400
9. Famine control	P	CCC	56	*
10. Disease damage assessment & control	H	ARS	1,659	4,000

1/ N = no source of estimate available
P = based on project staff judgment
H = supported by published information or from experts in the field

2/ ARS-Agricultural Research Service, ASCS-Agricultural Stabilization and Conservation Service, CCC-Commodity Credit Corporation, C&MS-Consumer and Marketing Service, ERS-Economic Research Service, FAS-Foreign Agricultural Service, FCIC, Federal Crop Insurance Corporation, IADS-International Agricultural Development Service, OIG-Office of the Inspector General, RCDS-Rural Community Development Service, SCS-Soil Conservation Service, SRS-Statistical Reporting Service,--Major interest lies in non-USDA agencies.

3/ The values estimated are based on anticipated gross savings and improvements. They were established on a unit basis, and then multiplied to represent the sum of all units within the industry. World benefits, when claimed, were generally calculated on the basis of values assigned for the U.S., with the unit value of benefits reduced. An asterisk (*) indicates that no estimate of benefits is available for that particular application.

Table 6. Agricultural Applications - Continued

	Applications	Source of estimates 1/	Interested USDA agency 2/	Annual U.S. benefits 3/	Annual world benefits 3/
				(Million dollars)	(Million dollars)
11.	Insect damage assessment & control	H	ARS	2,000	6,000
12.	Evaluation of damage to ornamentals	H	ARS	400	*
13.	Water pollution control	N	ARS	*	*
14.	Identification of perimeter areas of nematode infections	N	ARS	*	*
15.	Survey of damage from wildlife browse	N	-	*	*
16.	Census of weed areas	H	ARS	50	*
17.	Conservation needs inventory	H	SCS	*	*
18.	Disaster warning	H	-	200	600
19.	Soil mapping (improvements)	H	SCS	863	5,000
20.	Soil mapping (savings)	H	SCS	10	30
21.	Analysis of soil deficiencies	H	SCS	125	375
22.	Resource evaluation	H	SCS	4	*
23.	Recreation resource analysis and development	N	ERS SCS	*	*
24.	Watershed planning and control	H	SCS	*	*
25.	Evaluation of applications of new technology	P	ERS	10	*
26.	Topographic studies	N	-	*	*

Table 6. Agricultural Applications - Continued

Applications	Source of estimates 1/	Interested USDA agency 2/	Annual U.S. benefits 3/	Annual world benefits 3/
			(Million dollars)	(Million dollars)
27. Detailed plane leveling for intensive cropping	P	SCS	125	*
28. Erosion hazard analysis	H	SCS	500	*
29. Irrigation needs inventory	P	ERS SCS	250	1,000
30. Plant ecology analysis	N	-	*	*
31. Detection of salinity & other special soil features	P	ARS SCS	100	*
32. Seasonality studies of growth rates	N	ARS	*	*
33. Recreation site evaluation	P	SCS	10	*
34. Surveillance of algae and aquatic weed plant growth	H	ARS	15	*
35. Bird cover and habitat analysis	P	ARS	100	300
36. Detection of areas of unusual plant growth	P	ARS	100	500
37. Water impoundment area studies	H	SCS		*
38. Runoff and seepage analysis	H	SCS	500	*
39. Sedimentation studies	H	SCS	1	*
40. Water quality evaluation	N	ARS	*	*

Table 6. Agricultural Applications - Continued

	Applications	Source of estimates 1/	Interested USDA agency 2/	Annual U.S. benefits 3/	Annual world benefits 3/
				(Million dollars)	(Million dollars)
41.	Climatic analysis	N	-	*	*
42.	Agricultural geography	N	-	*	*
43.	Crop inventories	N	SRS	*	*
44.	Census applications	H	SRS	1	*
45.	Drainage planning	H	SCS	2	*
46.	Calculation of discharge capacity of valleys	P	SCS	10	*
47.	Land classification	H	ERS	12	40
48.	Land cover mapping	H	-	14	*
49.	Tax assessment mapping	H	-	82	*
50.	Ownership mapping (see plat mapping)		-	*	*
51.	Nuisance mapping	N	-	*	*
52.	Compliance control mapping	H	ASCS	13	*
53.	Regional planning and development	H	ERS	2	*
54.	Sequential urban - agricultural contact analysis	P	ERS	2	*
55.	Watershed development studies	H	ERS	10	*
56.	Agricultural sociological applications	H	ERS	2	*

Table 6. Agricultural Applications - Continued

	Applications	Source of estimates 1/	Interested USDA agency 2/	Annual U.S. benefits 3/	Annual world benefits 3/
				(Million dollars)	(Million dollars)
57.	Rural & suburban zoning	P	ERS	5	*
58.	Rural area development	H	RCDS	1	*
59.	Land use comparison and trends	H	ERS	6	*
60.	Market needs surveys	N	C&MS	*	*
61.	Plat mapping	H	-	150	300
62.	Population density maps	N	-	*	*
63.	Adjudication	N	OIG	*	*
64.	Highway route planning	P	-	1	*
65.	Mapping world agricultural land area	P	FAS	*	*
66.	Crop prediction and inventory	P	SRS	*	*
67.	Analysis of planting dates	H	ARS	*	*
68.	Harvest production information	H	SRS	*	*
69.	Transpiration analysis	P	ARS	*	*
70.	Site classifications	P	SCS	10	
71.	Predetermination of irrigation requirements	H	ARS	1,190	3,000
72.	Control of transportation of irrigation water	H	SCS	890	3,000

Table 6. Agricultural Applications - Continued

Applications	Source of estimates 1/	Interested USDA agency 2/	Annual U.S. benefits 3/	Annual world benefits 3/
			(Million dollars)	(Million dollars)
73. Capital needs mapping	P	ERS	10	*
74. Field patterns and organizations analysis	N	-	*	*
75. Water supply location	P	SCS	50	*
76. Farm practices analysis	P	ERS	5	*
77. Commercial farm field layout	P	SCS	180	500
78. Tree crop area census	P	SRS	*	*
79. Intensive localized uses (egg counts, livestock disease identification, etc.)	P	ARS	200	*
80. Water-borne and water related insect control	P	ARS	50	*
81. Large area land-scape planning	N	-	*	*
82. Domestic animal census	N	SRS	*	*
83. Farm building layout studies	P	-	125	400
84. Census of land improvements	H	-	50	*
85. Location of structural materials	N		*	*
86. Mechanization feasibility studies	N	-	*	*

Table 6. Agricultural Applications - Continued

	Applications	Source of estimates 1/	Interested USDA agency 2/	Annual U.S. benefits 3/	Annual world benefits 3/
				(Million dollars)	(Million dollars)
87.	Rural road maintenance	H	-	140	500
88.	Locating disease and insect resistant species	N	ARS	*	*
89.	Controlling spread of noxious plants	N	ARS	*	*
90.	Prediction for processing industry	H	SRS	375	*
91.	Forecasting climatic changes	P	-	100	300
92.	Reduction of losses from misuse of insecticides, fungicides, etc.	H	-	35	*
93.	Detecting heat in storage	N	-	*	*
94.	Inventory of grain storage	N	CCC	*	*
95.	Livestock disease identification	H	ARS	750	3,000
96.	Predetermination of egg hatchability	N	-	*	*
97	Prevention of marketing losses of agricultural products	N	C&MS	*	*
98.	Reduction of soil erosion losses from water and wind	H	SCS	400	*
99.	Evapotranspiration control	N	ARS	*	*

Table 6. Agricultural Applications - Continued

Applications	Source of estimates 1/	Interested USDA agency 2/	Annual U.S. benefits 3/	Annual world benefits 3/
			(Million dollars)	(Million dollars)
100. Off-shore temperature measurements	N	-	*	*
101. Scheduling field crop storage & processing	P	-	160	*
102. Rural roads--maintenance & construction	H	-	*	15,000
103. Educational uses of remote sensing	N	-	*	*
104. Operation of world food budget	N	ERS	*	*
105. Integrated transportation systems in developing agricultural economies	N	IADS		*
106. Recording agricultural history	N	-	*	*
107. Planning cultural development projects	N	-	*	*
108. Sample design	P	SRS	1	10
109. Publications uses	N	SCS	*	*
110. Plant species exploration	N	ARS	*	*
111. Development of aquatic agriculture	N	ARS SCS	*	*
112. Weather prediction and modification	N	-	*	*

Table 6. Agricultural Applications - Continued

	Applications	Source of estimates 1/	Interested USDA agency 2/	Annual U.S. benefits 3/	Annual world benefits 3/
				(Million dollars)	(Million dollars)
113.	Veterinary research--based on heat sensors	N	ARS	*	*
114.	Selective breeding of stock	N	ARS	*	*

Table 7. Forestry Applications

Applications	Source of estimates 1/	Interested USDA agency 2/	Annual U.S. benefits 3/	Annual world benefits 3/
			(Million dollars)	(Million dollars)
1. Assembly of historical records	N	FS	*	*
2. Water pollution control--related to forestry	P	FS SCS ARS	1	10
3. Forest areas evaluation--for purchase, exchange, etc.	P	FS	3	*
4. Transportation planning	N	FS	*	*
5. Cadastral applications	H	FS	*	*
6. Evaluating sociological aspects of economic development	N	ERS	*	*
7. Wildlife management	N	FS SCS	*	*

1/ N = no source of estimate available
P = based on project staff judgment
H = supported by published information or from experts in the field

2/ ARS-Agricultural Research Service, C&MS-Consumer and Marketing Service, ERS-Economic Research Service, FS-Forest Service, SCS-Soil Conservation Service, --Major interest lies in non-USDA agencies.

3/ The values estimated are based on anticipated savings and/or improvements. They were established on a unit basis, and then multiplied to represent the sum of all units within the industry. World benefits, when claimed, were generally calculated on the basis of values assigned for the U.S., with the unit value of benefits reduced. An asterisk (*) indicates that no estimate of benefits is available for that particular application.

Table 7. Forestry Applications - Continued

Applications	Source of estimates	Interested USDA agency [2/]	Annual U.S. benefits [3/]	Annual world benefits [3/]
			(Million dollars)	(Million dollars)
8. Watershed analysis and control programs	P	FS SCS	1	*
9. Ownership	N	FS	*	*
10. Tax mapping and evaluation	H	FS	8	8
11. Evaluation of change in land use	P	FS ERS	3	*
12. Mapping forest areas	N	FS	*	*
13. Compliance investigation and control	H	FS	2	*
14. Forest land use survey	P	FS ERS	7	98
15. Forest soil survey	H	FS SCS	98	300
16. Forest inventory	H	FS	9	125
17. Recreational resource evaluation	N	FS ERS	*	*
18. Forest site classification	H	FS	10	150
19. Forest mensuration	N	FS	*	*
20. Forest ecology classification	N	FS	*	*
21. Fish habitat classification	H	FS SCS	300	*
22. Fish inventory	N	FS SCS	*	*
23. Heat classification of plantation sites	P	FS	20	*

Table 7. Forestry Applications - Continued

Applications	Source of estimates 1/	Interested USDA agency 2/	Annual U.S. benefits 3/	Annual world benefits 3/
			(Million dollars)	(Million dollars)
24. Stream pollution analysis	P	FS SCS ARS	*	*
25. Snow depth measurement (included in agriculture)		FS SCS		
26. Studies of near-tundra areas	N	-	*	*
27. Valley discharge analysis	H	FS SCS	*	*
28. River basin planning	H	FS SCS	*	*
29. Scenic area evaluation	N	FS ERS	*	*
30. Planning vegetative types for game production	P	FS	5	50
31. Documentation of climate	N	FS ARS	*	*
32. Offshore temperature analysis	N	FS	*	*
33. Mapping mineral deficient & toxic areas	N	FS ARS	*	*
34. Land use inventory	H	FS ERS	3	39
35. Forest cover mapping	H	FS ERS	3	39
36. Site evaluation for reforestation	H	FS	6	*
37. Accessibility rating	P	FS	*	*
38. Delineation of disaster-prone areas	P	FS	20	*

Table 7. Forest Applications - Continued

	Applications	Source of estimates 1/	Interested USDA agency 2/	Annual U.S. benefits 3/	Annual world benefits 3/
				(Million dollars)	(Million dollars)
39.	Topographic evaluation	P	FS	2	*
40.	Engineering aspects--roads, mill sites, etc.	P	FS	*	*
41.	Inventory of disease and insect damage	H	FS ARS	150	2,000
42.	Control of harvest operations	P	FS	*	*
43.	Location and design of tree windbreaks	P	FS	10	100
44.	Recording mist levels	N	FS ARS	*	*
45.	Mist level as indicator for spray programs	N	FS ERS	*	*
46.	Measurement of recreational use	N	FS ERS	*	*
47.	Stream flow control	N	FS	*	*
48.	Locating desirable seed sources	N	FS	*	*
49.	Inventorying harvest of specialty products	P	FS ERS C&MS	*	*
50.	Location of recreational use sites	N	FS ERS	*	*
51.	Maximization of recreational use	N	FS ERS	*	*
52.	Location of major disturbance uses, such as pipe lines	N	FS	*	*
53.	Fire detection	H	FS	120	*

Table 7. Forestry Applications - Continued

Applications	Source of estimates 1/	Interested USDA agency 2/	Annual U.S. benefits 3/	Annual world benefits 3/
			(Million dollars)	(Million dollars)
54. Inventorying fire damaged areas	H	FS	39	*
55. Studying patterns & forms of fires	N	FS	*	*
56. Directing fire control work	N	FS	*	*
57. Tracking thunderstorms (covered under fire detection)		FS		
58. Evaluation of combustion levels (predetermination of fire hazard)	N	FS	*	*
59. Location and evaluation of insect damaged areas	H	FS	60	*
60. Location and evaluation of erosion areas	P	FS SCS	*	*
61. Evaluation of storm damage	P	FS	50	*
62. Disease detection, salvage and control	H	FS	50	*
63. Air pollution damage, evaluation and control	H	FS ARS	20	*
64. Location and evaluation of wildlife browse	N	FS	*	*
65. Analysis of areas of specialized control	P	FS	14	*
66. Location and evaluation of parasitic plants	P	FS	1	*

Table 7. Forestry Applications - Continued

	Applications	Source of estimates 1/	Interested USDA agency 2/	Annual U.S. benefits 3/	Annual world benefits 3/
				(Million dollars)	(Million dollars)
67.	Delineation of sites for restocking	H	FS	28	*
68.	Studying relationships between forest areas & climate	N	FS	*	*
69.	Detection of diseases and insects at critical points	P	FS	*	*
70.	Monitoring volcanic activity	N	-	*	*
71.	Search-rescue operations	P	FS	*	*

Table 8. Range Land Applications

Applications	Source of estimates 1/	Interested USDA agency 2/	Annual U.S. benefits 3/	Annual world benefits 3/
			(Million dollars)	(Million dollars)
1. Range land classification	H	SCS FS	8	40
2. Area inventory	H	SCS FS ASCS	25	250
3. Locating irrigable areas	H	SCS	1,500	10,000
4. Running inventory of range	H	SCS FS	4	40
5. Livestock inventory	N	SCS FS	130	1,000
6. Delineating crop production areas	N	SCS FS	*	*
7. Monitoring shifts in land use	N	ERS FS SCS	*	*

1/ N = no source of estimate available
P = based on project staff judgment
H = supported by published information or from experts in the field

2/ ARS-Agricultural Research Service, ASCS-Agricultural Stabilization and Conservation Service, C&MS-Consumer and Marketing Service, ERS-Economic Research Service, FS-Forest Service, OIG-Office of the Inspector General, REA-Rural Electrification Administration, SCS-Soil Conservation Service, SRS-Statistical Reporting Service, --Major interest lies in non-USDA agencies.

3/ The values estimated are based on anticipated savings and/or improvements. They were established on a unit basis, and then multiplied to represent the sum of all units within the industry. World benefits, when claimed, were generally calculated on the basis of values assigned for the U.S., with the unit value of benefits reduced. An asterisk (*) indicates that no estimate of benefits is available for that particular application.

Table 8. Range Land Applications - Continued

Applications	Source of estimates 1/	Interested USDA agency 2/	Annual U.S. benefits 3/	Annual world benefits 3/
			(Million dollars)	(Million dollars)
8. Reconnaissance soil surveys	H	SCS	15	150
9. Soil classification	H	SCS	220	25,000
10. Soil salinity analysis	P	SCS	10	100
11. Estimating range carrying capacity	H	FS SCS	500	5,000
12. Analysis of soil moisture conditions	N	SCS	*	*
13. Compliance control	H	ASCS FS		
14. Providing census information	N	SRS	*	*
15. Providing hydrologic information	N	FS SCS	*	*
16. Range resource inventory	P	ERS FS SCS	10	100
17. Conservation needs inventory	N	SCS	*	*
18. Plat mapping of ranches	N	-	*	*
19. Boundary identification	P	ERS	5	*
20. Mapping global range areas	H	-	*	*
21. Estimating ultimate yield potential	H	SCS FS	*	*
22. Determination of trend in condition	P	SCS FS	10	100
23. Improving weather forecasting	P		20	200

Table 8. Range Land Applications - Continued

Applications	Source of estimates 1/	Interested USDA agency 2/	Annual U.S. benefits 3/	Annual world benefits 3/
			(Million dollars)	(Million dollars)
24. Wildlife inventory	H	FS SCS	75	*
25. Mapping areas of mineral imbalance	P	SCS	10	*
26. Mapping vegetative zones	N	-	*	*
27. Mapping cover and condition	P	FS	*	*
28. Identifying areas of high response to inputs	N	ERS	*	*
29. Evaluating tundra range	H	-	*	300
30. Identifying areas of high oxygen consumption	N	ARS	*	*
31. Monitoring soil moisture utilization	N	ARS SCS	*	*
32. Monitoring feedlot and marketing activities	N	C&MS	*	*
33. Assessing plant population changes	P	ARS	6	50
34. Classifying the ecology of plant populations	N	ARS SCS	*	*
35. Wildlife habitat studies	P	FS SCS ASCS	50	250
36. Quantitative and qualitative improvement of water supplies	N	SCS	*	*
37. Mapping biomes	N	-	*	*

Table 8. Range Land Applications - Continued

Applications	Source of estimates 1/	Interested USDA agency 2/	Annual U.S. benefits 3/	Annual world benefits 3/
			(Million dollars)	(Million dollars)
38. Locating and mapping disaster areas	P	ASCS	50	250
39. Locating and controlling insect epidemics	H	ARS FS	160	800
40. Detecting diseased livestock	H	ARS	90	500
41. Locating and controlling plant diseases	H	ARS FS	23	120
42. Fire control	N	FS	*	*
43. Controlling noxious plants	P	ARS	4	40
44. Rodent and predator control	N	ARS	*	*
45. Weather modification	P	-	1,000	10,000
46. Locating and monitoring air pollution	N	ARS	*	*
47. Locating temporary grazing areas	H	FS SCS	110	1,000
48. Selecting wintering areas	H	FS SCS	55	*
49. Detecting loss of crop vigor	H	FS SCS	55	*
50. Planning physical setting of ranch facilities	H	FS SCS	350	*
51. Grazing cover enhancement	P	SCS	300	1,500
52. Overgrazing and compaction	N	SCS	*	*
53. Management of range stock movement	P	-	50	250

Table 8. Range Land Applications - Continued

	Applications	Source of estimates 1/	Interested USDA agency 2/	Annual U.S. benefits 3/	Annual world benefits 3/
				(Million dollars)	(Million dollars)
54.	Integrated pasture use and development programs	N	-	*	*
55.	Determining land trafficability for range use	N	-	*	*
56.	Stock handling and transportation development	N	-	*	500
57.	Assessing maintenance needs of facilities	H	-	4	*
58.	Evaluating compatability of stock to range	N	SCS FS	*	*
59.	Locating special use areas	P	SCS FS	10	*
60.	Financial reliability mapping	N	ERS	*	*
61.	Measuring of light intensity (ecology)	N	ARS	*	*
62.	Wildlife research	N	FS SCS	*	*
63.	Analysis of sand (and surface) movement	N	-	*	*
64.	Land use inventory	P	ERS	6	50
65.	Planning	P	Most USDA agencies	2	10
66.	Analysis of range development potential	N	FS SCS	*	*
67.	Tax base mapping	H		*	*

Table 8. Range Land Applications - Continued

	Application	Source of estimates 1/	Interested USDA agency 2/	Annual U.S. benefits 3/	Annual world benefits 3/
				(Million dollars)	(Million dollars)
68.	Legal aspects--adjudication, etc.	N	FS OIG	*	*
69.	Economic classification	H	ERS	1	*
70.	Irrigation resource analysis	H	SCS	*	*
71.	Utility planning and development	P	REA	1	10
72.	Identification of narcotic plants	N	ARS	*	*

3. That benefits can be derived from savings or improvements.

4. That there is a positive economic value (domestic and world-wide) for increased production of food and fiber.

5. That reductions in land, labor, and capital necessary for production of supplies of food and fiber constitutes a benefit.

6. That the value of savings and/or improvements generated through the use of remote sensing will be applied to gross benefits.

Values, where indicated, cannot be summed to obtain a total gross benefit to agriculture from remote sensing. There is overlap of applications among the three resource areas, and no values can yet be stated for many of the applications. In many instances one application would provide the information considered as a separate application in other instances. Thus, a complete land resources inventory might fulfill many of the requirements listed separately elsewhere. Also, complete economic analysis will require specification of operation/sensor packages, data dissemination procedures, and exact applications to be considered. In addition, much more detailed examination of potential cost-savings and improvements will be required.

Experts were consulted in many fields of study where applications showed promise of value. Their judgments were relied upon in making estimates of the value of savings and improvements. Their opinions were offered under circumstances that do not fairly permit them to be quoted. Backup material based on notes made during discussions with the experts has been prepared and is on file.

PROBLEMS OF SAMPLING IN USE OF REMOTE SENSING FROM SATELLITES

Even though substantial economic benefits could result from the use of sensors carried aboard earth-orbiting spacecraft such systems do possess important limitations. For example, an observation spacecraft is limited in its ability to observe a specific area at a specific time or on short notice because of possible cloud cover, lack of daylight, fixed orbital flight path, etc. Factors which are capable of influencing the value of agricultural data from space include the following: (1) type, detail, and format of direct and telemetered sensor data output; (2) frequency of data returns; and (3) geographic area for which data are relevant.

An attempt was made to identify and specify factors and procedures which will influence the reliability of agricultural data from an earth-orbiting sensor system. Specifically, it was sought to determine:

1. Optimum satellite agricultural reconnaissance system requirements as a function of feature discrimination.

2. Optimum output data requirements for interpretation as a function of detail and frequency of returns, geographic coverage, and availability of ancillary information.

3. Primary and ancillary data requirements for extrapolating information to areas adjacent to those remotely sensed by the system.

4. Requirements for achieving maximum acceptable accuracy for extrapolated data.

Extracting Agricultural Information from Imagery

The reliability of a statistic developed from an enumeration depends primarily upon the ability to classify correctly. A 100 percent reliability of classification of agricultural features from satellite imagery was assumed for this study.

The importance of spatial and temporal feature dispersion is indicated by the problem of estimating the total crop acreage or other land uses in a region. In the United States, 92.8 percent or 53 million acres of planted wheat acreage is distributed among 17 States having a combined area of 954 million acres. Depending upon the definition of a field and the average field size, there may be over one-half million "fields" distributed over the region. Some percentage must be located, identified, and perhaps measured for the development of a national crop statistic.

Factors influencing the area measurements of fields--image tilt, ground resolution, photographic scale, planimetric accuracy, film stretch, enlargement precision, etc.--are not necessarily compensating and could introduce a sizable error or bias in a final prediction based upon several hundred thousand discrete area measurements. Ideally, planimetric measurements for a large number of small highly dispersed features should be avoided if possible.

A primary reason for imaging at higher altitudes is larger coverage per frame. Other reasons are that the imaging systems used for the macroscopic view are also capable of a microscopic view (subject to vehicle constraint), e.g., areal terrain features ranging from a few square feet to thousands of square miles can be imaged at orbital altitudes.

Characteristics of the Feature

Data obtained from satellite sensing systems must be transformed into information. The effectiveness of a total system for this purpose depends upon:

1. Identification of the feature.

2. Compatibilities among different feature classes.

3. Temporal dispersion of feature members.

4. Spatial dispersion of feature members.

Systems designed for optimum detection, location and identification of feature class (X) is unlikely to be optimum for class (Y). The "ideal" system for maximum identification capability of all possible feature classes is one which performs spectrophotometric measurements from the visual to the microwave region of the electromagnetic spectrum. Presently, the earth can be imaged in any portion of the electromagnetic spectrum from ultraviolet to radar frequencies. In all likelihood, any image of the terrain will contain a representation of most feature classes of interest subject to theoretical electromagnetic interaction constraints which are primarily a function of wavelength. Every feature class has some optimum frequency band or bands within which it must be sensed for maximum enhancement. Fortunately, each individual feature class has more than one "color" (frequency response) associated with its electromagnetic interaction properties, permitting greater discrimination and classification as the "number" of possible classification tags increase.

Temporal dispersion of features influences recognition by altering feature signatures or ancillary information. Because the spectral reflectance of crops is a function of the growth stage, optimum sensing periods for one crop may be different for another thus giving rise to conflicts in scheduling.

Spatial dispersion of feature members is of primary importance to systems development and procedures for identification using either automated or conventional techniques of interpretation. A feature class containing many members distributed over a large region or a single feature, whose location is unknown, requires an areal search of the entire region. Locating a small areal feature on a photographic or television frame with a coverage of 3600 square nautical miles and 10 foot ground resolution is difficult unless the feature is highly enhanced on the imagery. As the number of feature members (small in area relative to a finite region) increase, time and cost of an enumeration increase. A feature such as wheat might require the location and identification of one-half million feature members (fields).

Sampling Techniques

The reliability levels of agricultural data returns from a space system are related to the capability of sensors to search and identify, measure and sum feature acreage (crops) spatially dispersed over millions of acres and temporally dispersed over some span of time. The entire United States as an area of interest can be photographed from a polar orbiting satellite with a ground resolution of 10-20 feet at 200 nautical miles in 22 days with 1 degree longitude swath widths at any specified hour ($\pm$ 2 hours). The quantity of useful, useless, and redundant information of such a large terrain complex as the entire United States is very nearly infinite, giving rise to a major problem in the functional classification of the useful interacting areal environmental units.

This study concludes that if the areal environmental units (crops) can be identified from photographs, areal aggregates can be sampled by the dot technique (a 2-dimensional random spatial distribution of dots over the area of interest) in order to make inferences about the total area of the environmental units. For a given space system the statistical reliability of agricultural data extrapolated from areas adjacent to those imaged decreases as orbital path spacings increase.

PERSPECTIVE

The research summarized in the preceding pages surveys the potential uses of remote sensing in agriculture and forestry and suggest how mankind might benefit from its use. The number and range of feasible applications appear to be great and magnitudes of potential economic benefits substantial. Still needed are in-depth studies of the potential economic benefits that could be derived in the 1970's from those applications in agriculture and forestry that appear feasible within the existing and future state of the arts. Secondary and tertiary benefits need further study.

In the present stage of development of remote sensing, it is difficult to accurately predict the direction of development and consequent applications. A USDA Remote Sensing Task Force recently considered a National Program of Research for Agriculture and Forestry Remote Sensing. In the Task Force's deliberations, emphasis was on remote sensing as a tool to carry out USDA functions. In this context there are at least twelve possible areas where the benefits of remote sensing appear to offer significant benefits to USDA agencies between 1970 and 1980 in carrying out their charted functions.

1. Government compliance checking--securing photography and certification
2. River basin planning--for watershed protection and flood control
3. Snow surveying
4. Soil mapping
5. Making crop forecasts (conditions) and estimating harvest
6. Making western range condition surveys and livestock count
7. Detecting selected crop diseases and insect outbreaks and locating witchweed growth
8. Inventorying natural resources--land use and water resources
9. Detecting and mapping forest fires
10. Making surveys to aid in assessing carrying capacity for domestic livestock and wildlife
11. Detecting forest insect and disease outbreaks
12. Appraising forest fire hazard levels.

Although additional research and development still needs to be carried out in these application areas, it was estimated that the annual cost-benefit ratio would be favorable by 1975.

Future cost-benefit studies must assess the potential of remote sensing for the improvement of agriculture and forestry programs that depend upon the rapid accumulation, analysis, and application of information on crops, forests, range, soils, and water conditions. To guide planning and budgeting of research and development of remote sensing techniques in agriculture and forestry, in-depth cost-benefit studies must be made for potential applications as they are identified.

Within the limits of available funds, the Economic Research Service (ERS) of the Department of Agriculture intends to continue its research to provide guides for an economic optimum long-range program of research and operations in the acquisition of data on agriculture and related resources from airplanes and from space platforms. Research is currently being directed to development of a land use classification system that will utilize imagery expected from the Earth Resources Technology Satellite to develop improved land use inventories. In its research, ERS will attempt to keep the Department officials informed on the range of potential applications and benefits associated with various levels of technical capabilities of sensing and data interpretation. Initial analyses will be refined and expanded as additional applications of remote sensing emerge from technological advancements.

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